The Theoretical Approaches to Improve Performance in Genetics and Develop Related Attitudes in Taiwanese Secondary Schools

*Yu-Chien Chu[1] & Norman Reid[1, 2]

[1]*Department of Educational Studies*
University of Glasgow, U.K.
[2]*University of Dundee, U.K.*
**E-mail(s): bomichu@gmail.com*

Abstract. *This study aimed to review younger secondary students' learning problems in genetics and attempted to improve their knowledge and literacy through the presentation of theoretical approaches. A review of literature on genetics learning was provided to explore the specific areas of difficulty and to relate these to the measured working memory capacity of Taiwanese students (age 13-14). Results pointed to that working memory capacity was the critical factor in learning genetics at this age. Based on the findings, a set of curriculum materials of genetics was deliberately constructed in line with the theoretical approaches, which were to minimise demands on the working memory, as well as to encourage attitude development.*

361 students from two secondary schools were included by purposive sampling in Taipei County, Taiwan, which were assigned to the experiential group (theoretical approaches) and control group (traditional approaches) respectively. The results showed that (1) the performance of the experiential group was found to be significantly better than the control group (p<0.001). (2) Numerous comparisons of attitudes between two groups revealed that attitudes of social awareness as well as attitudes towards aspects of the learning processes involved were more positive for the experiential group. All of this revealed fascinating insights into the development of learners' thought as well as highlighting the value of the theoretical approaches in bringing significant benefit to learners.

Keywords. Attitudes, Genetics learning, Performance, Theoretical approaches.

1. Introduction

Learning is not just the transferring of knowledge from the teacher to the learner. It is an understanding process where relatively permanent changes are caused by information and experience. These changes do not solely refer to outcomes of the learner's behaviour that are manifestly observable, but also to attitudes, feelings and intellectual processes that may not be so obvious [1]. Learning for understanding can be achieved if educators make the effort to find out what students' conceptions of learning are and what constitutes understanding.

Genetics is often thought of as a subject or a topic in biology that is important and even more in these days and age where its applications are ubiquitous and even the cause of many debates. However, due to the nature of the subject matter and the way learning processes occur and, possibly, the way it is being taught, the understanding of genetics ideas of the majority of students is thought to be very poor and full of confusions and alternative views. Thus, this study had sought to explore the learning difficulties in genetics and to identify possible ways forward.

2. Literature Review

Science education aims not only to transmit the knowledge and prepare for advanced study or a possible future carrier, but also to cultivate students to be citizens in modern societies which are now highly dependent upon scientific and technological advances [2], which means it aims to promote a positive attitude towards engaging with science and cultivate a person's development of scientific literacy [3]. This implies helping students to be interested in and understand the world around them, to engage in the discourses of and about science, to be sceptical and question of claims made by others about scientific matters, and to make informed decisions about the environment and their own health and well-being [4].

The study of genetics can offer insights into

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the way the living world works. However, any review of the literature about school and university students in learning genetics leads to the inescapable conclusion that students consider genetics difficult to learn and many misconceptions and misunderstandings can arise. Overall, genetics is an important theme for all learners but it is an area where there are major difficulties in understanding [5]. Literature reviews about school and university students' difficulties when learning genetics and several major reasons as being problematic were extracted:

2.1 Genetics subject itself

- *Nature of scientific knowledge*: Genetics is one of the most dynamic research disciplines within the natural sciences. It is a steady accumulation and might be changing in time and open to debate [6].
- *Complexity*: Genetics concepts refer to different levels of biological organisation (Figure 1) and students have difficulties with linking these different genetics concepts and processes with these different levels [7]. It is because several levels of organisation must be integrated in order to understand the processes underlying genetic phenomena and to grasp the overall picture of genetics. In addition, the levels of organisation, sometimes, lie both within a single discipline of the same/different chapter(s) while also involving other disciplines [8]. Because the working memory has a limited capacity, this is likely to bring about an information overload.

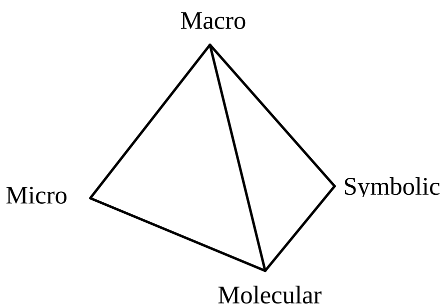

Figure 1. The pyramid of genetics concepts.

- *Terminological language*: Language development and conceptual development are inextricably linked. Firstly, understanding science is more than just 'knowing the meaning' of particular words and terms, it is about 'making meaning' through exploring how these words and terms relate to each other. One of the biggest problems of language in genetics is the complex and vast technical vocabulary. Students have the problem of learning the new and abstract words, and at the same time learning new concepts in that vocabulary [9]. According to Johnstone (1991), an unfamiliar word or known word in an unfamiliar context takes up valuable working memory space [7].
- *Mathematical requirement*: Bahar *et al*. (1999a) noted that mathematical expressions, which are symbolic, cause problems. In addition, students have difficulties in transferring the mathematical knowledge and insights from one context to another [5].

2.2 Differences in an individual cognitive developmental nature

According to Piaget's cognitive development theory, a student's ability to deal with abstract concepts in meaningful learning is correlated with his/her stage of cognitive development. Many genetics concepts require abstract thinking. Unless the student's has reached the level of thinking, he/she will not be able to cope adequately with these ideas. In order to learn meaningfully, students must relate new knowledge to what they already know [10], 1968). The existing knowledge and how it interacts with new knowledge determine the degrees of meaningful learning. If these are in conflict with accepted scientific ideas, new learning will be affected and misconceptions may establish, and further, these alternative conceptions and misconceptions will interfere with later study [7]. Obviously, these should be taken into account by teachers when teaching.

From the information processing perspective, the working memory can easily be overloaded in learning situations when the amount of information exceeds the upper limit of the working memory space [11]. For adolescents, this can happen more easily because of their undeveloped capacity. Nevertheless, by chunking, it is possible to reduce the load on the working memory although the capacity of the working memory cannot be changed [12]. That means the working memory improves if the pieces of information are familiar, frequently used, or logically related to each other. On the other hand, it can be easily overloaded when the new knowledge is large, unfamiliar, irrelevant or abstract and thus cause learning difficulties [11]. Moreover, various researches found that working memory capacity has significant effects on students' problem solving performance (e.g. [13]). Thus, the working memory capacity can be considered to be likely to be one of the key factors effecting the learning of genetics in secondary schools. However, if the teaching strategy can take into account a student's limited working memory capacity as a limiting factor in order to help a student to operate beyond his/her capacity, a student with a small working memory space still could be able to learn successfully [14].

2.3 Purpose of the study

Thus, the purpose of this study is to investigate the situation relating to learning of genetics in secondary schools, to offer strategies and approaches which will reduce students' difficulties in genetics, these being based on the accepted understanding of psychological reasons which bring about difficulties for students. Using established models of learning and research evidence about learning in sciences, the aim is to test some ways forward which are likely to improve the situation in the learning of genetics. This testing will involve not only the investigation of student performance in genetics tests but will also seek to explore the ways attitudes are affected by the new approaches.

3. Methodology

The participants of this study included 361 first year students of public secondary schools in the north of Taiwan. These students, typical secondary school students, had a mean age of 14. The new teaching material was applied to 180 students from 6 biology classes in two schools as the experimental group. The control group was 181 students from 6 biology classes who were from the same two schools as but taught by the traditional way. They were taught by the same teacher in one school, so two teachers in total were involved in this study. This study used comparing the experimental group and the control group to explore how theoretical approaches promote students' conceptual understanding and attitudes development about genetics.

3.1 The study instruments

Based on student-oriented interactive approach learning [15] and the information processing approach introduced by Johnstone (1993) [16] , we developed a new teaching instruction that support students' acquisition knowledge by interacting in groups and make connections between the academic genetics content and the student's everyday world. The lessons were presented under five themes: basic terminology, theory of heredity, human inheritance, sex determination, and genetics in our lives (nine hours of teaching involved) (Three examples shown in Appendix). It was deliberately constructed to:

- Organise the teaching materials carefully to relate to students' prior knowledge and experiences enabling pupils to build on existing knowledge and enabling them to assimilate and transfer new learning into the long-term memory. In the learning situation, students are encouraged to describe their observations about the phenomenon, gain an intuitive comprehension of it, and connect it to their personal experiences [17].
- Minimise demands of the working memory by highlighting the information to which the subject must attend, carefully sequencing and presenting the ideas step by step, and reducing to a bare minimum numbers of items of information that requires the attention of students. The information should be presented to the students in a language which should be easy enough to understand, and even use learners' language by setting them to interact in groups [16].
- Support students' ability to make sense of their observations and intuitive comprehension, and to use various representations to guide the direction of their thinking. Students are encouraged to manipulate and link multiple representations and generate simple rules or hypotheses to explain what they have observed [18].
- Relate closely to life and society and involve the learners in some interaction and discussion over key issues. By experience different views of the same issue, students are encouraged to recognize the many facets of real-life decision taking [15].

3.2 Procedure

The main experiment focused on secondary school students who were separated into the experimental group and the control group. The experimental group was taught using new teaching approaches and the control group was taught by normal teaching ways. Very often, the traditional strategies for teaching biology/ genetics rely on the teacher explanation and textbooks. After instruction, both groups were evaluated in terms of performance and attitude development in order to find out whether the teaching approaches were helping students in their learning and understanding in genetics as well as whether attitudes toward genetics and its social implications were developing.

3.3 Data collection and analysis

The following assessment tasks were used:

1. The measure of the working memory space capacity of the learners was used the figural intersection test [19];
2. The learners' performance included the scores of school examination and word association test [20]; and
3. The attitude questionnaire was used to investigate various students' insights into how they think and the way they evaluate situations and experience about genetics [21].

After collecting the data, every student' responses to each question were converted into a code and the data stored in a spreadsheet. Using the spreadsheet, the codes were used to calculate frequencies, percentages, and comparison groups.

4. Result

First of all, Taiwanese students' results of the figural intersection test for measuring the working memory capacity was 5.2±1.4 (age 14), which was consistent with the findings of other research studies [22]. Also, there was a significant correlation between students' outcomes in learning genetics and their working memory capacity ($p<0.001$). High working memory students performed better in the genetics examinations than low working memory students. Pamela Reid's (2002) showed working memory will only show correlation if the teaching or the assessment makes a demand on the working memory, so that those with higher working memory capacity have an advantage. Because of the structure of the genetics knowledge, genetics certainly has the potential to generate an information overload.

After instruction, students were evaluated in terms of performance and attitudes development. The results showed that the experimental group performed significantly better than the control group in both school examination and word association test (Table 1). Also, the improvements of two tests in the mean scores are large (6.4 and 7.6). The effectiveness of the new teaching material has therefore been shown to bring about a marked consistent improvement in students' performance.

Table1. The performances of students in genetics learning.

	Experimental group	Control group	t-test
School Examination	56.5±21.4	50.1±19.7	3.0 $p<0.01$
Word Association Test	26.9±12.8	19.3±10.9	6.0 $p<0.001$

Another important factor influencing success in learning relate to attitudes. In general, it is encouraging that around 50% of both the experimental group and the control group from secondary school enjoyed and could understand the genetics course as well as over 60% of students tended to see genetics as interesting, important, and related to their life, even they thought genetics is difficult, too mathematical, and too much to learn.

Comparing the experimental group with the control group about their feelings about the genetics course, it was found that more than 48.3% students of the experimental group had enjoyed the genetics course and they tended to enjoy the genetics course more than the control group ($p<0.01$). More students in the control group thought the genetics course was too much to learn. ($p<0.001$). The new teaching material, in fact, covered the same ground. This may reflect of way of minimising demands of the working memory. When students were asked if he/she can understand genetics in the class, the pattern of difference between two groups is quite complex. The experimental group tended to agree more or be neutral. However, less of them strongly agreed. Perhaps, quite a few of the experimental group were more confident that they understood genetics than the control group students, with some of the experimental group being more realistic: they appreciated more that genetics is difficult.

Studying students' attitudes and opinions about genetics applied in our lives, the results showed that the experimental group were more conservative. As shown on Table 2, in (a) question, although around 60% of students in both groups agreed that biotechnology will benefit our lives, there is a trend for the experimental group to move in towards the central position. It is possible that they were exposed to several social issues about genetics and realized the realities. In addition, students in the experimental group thought about ethic and moral issues more. In addition, it is worth noting that the experimental group students doubted if they will buy GM food, but the control group students tended to be even more hesitant. The experimental group strongly disagreed about cloning very talented people to benefit the society. Only 35% of students believe government has good intentions to the society.

Table 2: The results of questionnaire about genetics applied in our lives.

%		Strongly agree	Agree	Uncertain	Disagree	Strongly disagree	x^2
(a)	Biotechnology will benefit our lives.	19 23	40 40	36 29	2 5	3 3	6.6 (df3) p<0.05
(b)	Science research will progress slowly if government imposes strict rules about biotechnology.	3 8	15 9	47 46	22 24	13 13	0.6 (df3) No sig.
(c)	Parents have right to terminate pregnancy when they find the fetus with genetic disease.	17 22	25 27	32 30	17 13	9 8	5.5 (df4) No sig.
(d)	I am willing to buy GM food.	3 3	8 14	60 45	17 21	11 17	19.1 (df4) p<0.001
(e)	Cloning should be allowed to help cure diseases.	10 18	18 32	34 32	22 10	16 8	53.2 (df4) p<0.001
(f)	It would be good to clone very talented people for the benefit of society.	5 12	9 13	24 29	18 16	44 29	25.4 (df4) p<0.001

5. Discussion

The new teaching material developed was based on evidence derived from former research. The aim was to improve pupils' learning in genetics, especially conceptual understanding, to develop positive attitudes and growing awareness of the social implications of genetics. The new materials were deliberately constructed to minimise demands of working memory in that this is known to be a key factor which hinders understanding. They were also designed to relate closely to life and society and to involve the learners in some interaction and discussion over key issues.

Generally, students enjoyed and could understand the genetics course. They tended to see genetics as interesting, important, and related to their life, even they thought genetics is difficult, too mathematical, and too much to learn. Students who had experienced the new teaching material have improved positive attitudes and social awareness. They expressed more enjoyment, were more satisfied and realistic and thought more about ethical and moral issues. On the other hand, students who were taught by the traditional way tended to have more complaints, such as too much to learn, too much mathematics, and boring.

Overall, although the new teaching material had had a significant impact, there is clearly more to be done. Genetics still stands out poorly when compared to other parts of biology. The curriculum in genetics is abstract with much terminology and symbolism. These really have no place in a school syllabus and the students are clearly more perceptive than the curriculum planners. According to Hussein (2006), *a poor curriculum and teaching will tend to generate negative attitudes and this may lead to poor performance in tests and examinations. Good performance in tests and examinations will tend to generate better attitudes. Thus, attitudes and success are highly linked and each affects each other* [23].

However, it should be pointed out that all conclusions derived from this study must be treated tentatively. Inevitably, any new approach will have a novelty factor which may enhance performance. Nonetheless, the evidence taken together does support the hypothesis that learning arranged in line with information processing insights is more effective. In addition, the strategies used were designed in line with understandings of the ways attitudes develop and the effectiveness of these approaches has been demonstrated. In sum, the use of the teaching material had clearly generated better attitudes and improved performance. This was an example showing how the application of a well-attested educational model can bring real benefits for the learners.

In the light of the findings of the present research, the following strategies are recommended for implementation in genetics course of secondary school:

1. Attractive teaching material is a universal way for inspiring learning motivation.
2. Students' prior knowledge often does not conform to scientifically accepted principles and these ideas may serve as a foundation upon which new learning may be built. Obviously, these ideas should be taken into account by teachers; if they are not, and if they are erroneous, they could interfere with new learning. The results from this study can serve to help teachers plan more effectively and to select the best ways for introducing learners to genetics.
3. Cognitive styles may influence the learning of genetics. However, it is almost impossible to meet the needs of all the learning styles in a class of students. Nonetheless, the teacher should be aware that there will be variations in learning styles.
4. The nature of genetics knowledge certainly has the potential to cause the working memory to overload. When a new concept is introduced to the learners, the teacher should control the amount of useful information which the learner has to process and can also limit the extraneous distracting information in a learning situation, so that the working memory overload is minimised.
5. The teaching materials can be designed around applications and life experiences to create a more familiar context for the learning process (to concrete thinking). The learners can construct new concept based on the knowledge they already have. These should help learners developing positive attitudes, minimise working memory overloading, facilitate cognitive development toward formal thinking, and/or enable students to build on existing knowledge and assimilate and transfer new learning into the long-term memory.
6. Learning by means of groups with the materials can provide opportunities for learners to participate and learn through peer's language and group competition in order to increase motivation and improve understanding, which will lead to improve students' attitudes towards a subject.
7. The focus in teaching genetics should be more applications-led and should enable the learners to realise how genetics could be used positively in making decisions and choices.

As in any other research, questions have arisen from this study and they can be point of departure for further research. There are some suggestions offered: Firstly, the study has revealed that an understanding of certain key topics is extremely important for further study in genetics. For example, an understanding of mitosis and meiosis is very important for understanding Mendelism. Thus, more research is needed to explore the reasons for these relationships and, more importantly, how to improve the learning of these foundational concepts. Secondly, as mentioned in the last section, the research can go further. The longer term effects of such teaching approaches needs explored as well as the need to check the findings by means of, perhaps, interviews.

Moreover, the new teaching material developed in genetics is an example, which relates to effective and efficient learning as well as the development of positive attitudes. The approach can be used as a means for applying to other cognate subjects. If there was a consistent development across many subject areas, following parallel approaches, then there would be the need for a major research project to measure the outcomes and to pinpoint further areas needing exploration and development. Finally, it is hoped that this study will be able to contribute to the development of genetics as a school discipline so that students who complete courses will be equipped and motivated to make genetics learning more meaningful and practical to students, as well as being able to make future contributions based in genetics as well as many other career options.

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Appendix

Three examples of the genetics teaching material in this study

Example 1: Genetics in our lives

Teacher's guide:

(a) Form groups of three pupils and allow them to sit around a desk.
(b) Give each group a set of reading information for further discussion.
(c) Give each student a copy of the sheet entitled, "Cloning Humans: Right or Wrong?"
(d) Allow pupils abut 30 minutes to discuss the questions and write down their agreed answers.
(e) After the group work, ask how many groups favoured human cloning and how many were against it.

(f) Select some groups and ask them for the most powerful reasons they had for or against it.
(g) If time allows, let the students start the exercise, “Homework”. This can be completed at home.

Students’ material:

Cloning Humans: Right or Wrong?

> Please read the papers that your teacher gives you and discuss the following questions.
> You will be working in a small group of about three.
> Do not try to work on your own!!
> After you have discussed each question, you can take it in turns to record your agreed answers.
> One of you may be asked to report back on your answers to question 6.

(1) As a group, list as many benefits you can think of which could come from human cloning.
(2) What are the drawbacks which might occur with human cloning?
(3) Do you think cloning can cause ethical (things about right and wrong) problems?
(4) There are three types of parents: gene parents, delivery parents, and care parents.
What kinds of legal problems might arise?
(5) What do you think different religions might have to say about human cloning?
Will it change our beliefs?
(6) As a group, do you think human cloning is a good idea? Give your reasons.

. Homework

Please write a letter to the British Queen (no more than 6 sentences).

Tell her your opinions about human cloning.

Give her some reasons why you recommend or reject that human cloning should be allowed in the UK.

Example 2: Genetics in our lives

Teacher’s guide:
(a) Take students to the computer room.
(b) Give each student the sheet entitled, “Genetics in Our Lives”
(c) Allow students to follow the instructions, finding the web sites and completing the answers.

Students’ material:

Genetics in our lives

Shrek said:
I’m going to marry Princess Fiona. The king of the kingdom of far far away asks us to do genetic counselling in the hospital.

Princess Fiona said:
I saw some food in the supermarket is labelled GM Food. What’s that? And if I eat that, does that make me become normal both day and night.

Prince charming said:
Last week’s news indicated that scientists are researching on human cloning! If it is possible, I am going to clone a lot of myself, charming human being.

Donkey said:
I heard genetic engineering and biotechnology are very hot nowadays. They can help agriculture breeding, but also produce medicines. Maybe I’ll become a horse one day!

Genetics is more and more important in our lives.

Please surf the following websites and answer questions.

Part 1: Genetic counselling

http://sp1.cto.doh.gov.tw/doctor/book/ch02/book2_2.htm
(1) What is genetic counselling?
(2) Who needs to do this?

http://nature.ckps.tpc.edu.tw/6b/%BF%F2%B6%C7/tree-chap8.htm
(3) What is the carrier of a genetic disease? Answer: ___________
(A) A patient with a genetic disease.
(B) A healthy person who has a disease gene. (e.g. genotype is Aa)

http://www.commonhealth.com.tw/New_Life/baby/exam2.htm

Pedigree is very important when we do genetic counselling.

(4) How do doctors know you are not a carrier of genetic disease?

http://content.edu.tw/junior/bio/tc_wc/textbook/ch08/supply8-6-1.htm

(5) How is genetic counselling carried out?

(6) If you needed it, where could receive genetic counselling?
(Choose one where is the nearest your home.)

Example 3: Human inheritance

Teacher's guide:

(a) Form groups of four and give each pupil the papers entitled Gamete Combination.

(b) Allow the groups to work through the exercises for the whole lesson.

Students' material:

Human Inheritance (1): Gamete combination

Using Punnett squares allows us to predict the ratios in crosses.

These ratios may differ from those in experimental crosses.

Part 1

The double-fold/single-edged eyelid is a trait inherited from our parents (see the figure). The gene for double-fold eyelid is dominant (R) to that for single-edged eyelid (r).

If the genotypes of a couple are Rr x Rr, please use the Punnett squares to predict the ratios in crosses.

The types of offspring genotype ______ ______ ______ ______

The phenotype ratio of offspring ______________________________

Part 2

Use the cards to represent chromosomes. The letter on the card represents a gene:

R is the gene of double-fold eyelid and r is the gene of single-edged eyelid.

R **r** x **R** **r**

(1) You will be working in a group of three:
One member will act as the *father*;
One member will act as the *mother*; and
One member will act as the *child*.

(2) The father will hold the grey cards and the mother the white cards. The grey cards represent the chromosomes in the father's cell, and two white cards represent those in the mother's cell.

(3) One student is to play the father taking two grey cards, and the other student is to play the mother taking two white cards. Place the cards face to yourself.

(4) The third student (playing child) picks one card from the father and one from the mother without looking and then links them together. (So he/she will get one grey card and one white card). This means the gene combination of the first offspring.

(5) Record this result on the following table, and then give the cards back to the parents.

(6) Repeat 3 times.

(7) List the genotypes obtained. Beside each genotypes state the phenotype.

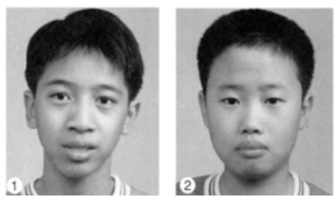
(8) Repeat 16 times.

Number	Genotype	Phenotype	Number	Genotype	Phenotype	Number	Genotype	Phenotype	Number	Genotype	Phenotype	Number	Genotype	Phenotype
1			5			9			13			17		
2			6			10			14			18		
3			7			11			15			19		
4			8			12			16			20		

Answer the following questions.

1. Work out the ratio of phenotype from data 1 to 4.
   The double-fold eyelid's number:
   The single-edged eyelid's number:
   The double-fold eyelid : the single-edged eyelid =

2. Work out the ratio of phenotype from data 1 to 20.
   The double-fold eyelid's number:
   The single-edged eyelid's number:
   The double-fold eyelid : the single-edged eyelid =



Double-fold eyelid/Single-edged eyelid

3. Collect all data from all classmates and work out the ratio of phenotype.
   The double-fold eyelid's number:
   The single-edged eyelid's number:
   The double-fold eyelid : the single-edged eyelid =

4. Arrange your data:

Punnett square to show the ratio phenotype is
From data 1 to 4 the ratio of phenotype is
From data 1 to 20 the ratio of phenotype is
From all classmates' data ratio of phenotype is

5. If we compare the ratio of dominant and recessive in four children family and twenty children family, which result is close to the theory?

6. After collecting the data from all classmates, how does the ratio of dominant and recessive compare between this experiment and theory?

7. Explain why the actual ratios may differ from the predicted ratios.